Harbor/Mooring Harbor Defense Concept

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LONG-TERM GOALS

The long-term goal of this work is an integrated defense system that provides protection of Navy assets, while in port, from the threat posed by covert swimmers. The general concept is to hail, deter, and/or incapacitate the threat by directing a controlled level of low-frequency acoustic energy at the target location. At the system level, the concept requires combining elements of target detection, classification, and tracking, localized fire control to direct acoustic energy using emplaced acoustic sources, and sources capable of delivering energy commensurate with the extant defense requirements.

OBJECTIVES

This work is a collaborative effort with many participants. The participants and individual contributions are listed below. Principle objective of this work is integrating the individual components into a working system, culminating in a demonstration scheduled during the 3rd quarter of 2008. A key technical objective of this work addresses the question: can a dynamic complex acoustic field be directed onto a target with enough energy to cause deterrence, disablement, or physical damage to cause the swimmer mission to be aborted?

APPROACH

The approach involves collaborative efforts in directive source and acoustic propagation modeling, mobilization of appropriate low-frequency acoustic sources (by acquisition or prototype design), assembly and testing of equipment for validation in a controlled environment, and final prototyping and testing in an operational environment. To meet the proposed objectives, a multi-phased approach will be taken including analytic and numerical computations along with experimental validation. The work will progress from understanding the requirements of, and demonstrating numerically, the ability to direct and propagate low-frequency acoustic energy in a simple 2-D waveguide, to a prototype system test in an operational environment. A major component of the effort will involve integrating proposed source characteristics/configurations/control into the numerical modeling codes. This component will include collaboration with PSU Center for Acoustics and Vibration (CAV) and BAE Systems for validation of source concepts. Another major factor will be establishing an adaptive computational framework for calculating acoustic energy loss that responds to spatial and temporal characteristics of the harbor environment in conjunction with the sources proposed/used for the program. In particular, for harbor acoustic characterization, the low frequency harbor acoustics and harbor transfer function must adapt to the repositioning of source(s), tidal and other diel variations, and movable scatterers (such as ships).

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14. ABSTRACT
The long-term goal of this work is an integrated defense system that provides protection of Navy assets, while in port, from the threat posed by covert swimmers. The general concept is to hail, deter, and/or incapacitate the threat by directing a controlled level of low-frequency acoustic energy at the target location. At the system level, the concept requires combining elements of target detection, classification, and tracking, localized fire control to direct acoustic energy using emplaced acoustic sources, and sources capable of delivering energy commensurate with the extant defense requirements

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The initial phase of work effort will be an expanded feasibility study of acoustic transmission calculations in idealized harbor-like environments. For a given source configuration and environment, formation of an acoustic *hot zone* will be evaluated by contour levels indicating intensity and extent of regions corresponding to where a swimmer would likely detect the signal, be deterred, or be incapacitated (exact levels to be determined in a separate study, but a preliminary literature search suggests 140 dB re 1 uPa for diver awareness of irradiation and (TBD) dB for immobilization [1]. The feasibility and relative efficiency of different source types will be investigated analytically and numerically for both narrow- and broad-band signals. Sources will be integrated into a common "benchmark" harbor model environment for comparison of the computed acoustic fields. Modeling will also be used for determining the location, number, and power requirements of acoustic sources necessary to achieve dynamic focusing capabilities in a given harbor environment. Source capability will be demonstrated numerically by plots of acoustic intensity and energy flux density as a function of position and depth.

It is anticipated that modeling efforts will continue over the duration of this project. Propagation modeling efforts will start with an idealized 2-D harbor environment incorporating very simple boundaries and typical harbor depths. The calculations will be extended to more complex environments, by varying the harbor bottom type, adding thermoclines, introducing ships and including permanent harbor structures such as piers or breakwaters. The latter cases, which represent the introduction of strong acoustic scatterers into the environment, will show the enhancement/degradation and/or displacement of the *hot zone* caused by including typical harbor structures. Initial 2-D waveguide modeling efforts will progress to 3-D modeling work in order to make predictions for the specific harbor environment where demonstration project will be conducted. As dictated by the chosen harbor environments, as features are added, modeling will progress, as necessary, from traditional approaches used in ocean acoustic propagation modeling such as normal modes or parabolic equation methods, to more general finite element or boundary element methods [2]. The overall effort will require dedicated computational facilities as well as the potential for a significant effort in adapting or developing propagation codes to meet project requirements. At project completion, the accumulated modeling capabilities will be repackaged to provide harbor deterrent system design capabilities for specific ports. The design system prototype will be configured and provided for Navy and Coast Guard use.

Experimentally, and in collaboration with the CAV, ARL/UT, NRL and BAE systems, the work will progress from a controlled study to an operational prototype. The full system prototype will be demonstrated in a real harbor in spring 2008. In FY 06 and 07, after demonstrating numerically the ability to focus energy in relatively simple environments, computational results have been validated by experimental work in controlled environments. These tests will demonstrate, using sources and an array of receiving hydrophones and an underwater human surrogate gel model ("gel-man", NRL), that an acoustic *hot zone* can be created and dynamically controlled within a simple waveguide, and the impact on tissue and thoracic cavity features gauged as a function of time and intensity. At this stage, the work will seek to demonstrate the ability to deliver a stepped level of acoustic intensity to a specified interrogation region. Demonstration and engineering tests will progress from fully controlled environments such as laboratory test tanks, an outdoor flooded quarry (Jacksonville, PA), to a real harbor environment (Coddington Cove, Newport, RI).

In FY 08, a demonstration in a real harbor environment with a prototype system will be planned and executed. The harbor location is anticipated to be Coddington Cove, Newport, RI. The required effort prior to an operational environment demonstration is extensive. For a real environment and a convincing prototype, it is important to demonstrate subsystem linkage, total system integration and simplicity of use, in addition to the obvious metrics of capability. Acoustic sources, a *gel-man* model and the receiving array of hydrophones will be adapted from fieldwork completed in 07. The scope of the prototype system will include demonstrating a response at the location of swimmers or other targets which may be deployed during this phase at the discretion of the program manager or other sponsoring agency. For validation purposes, using the modeling tools developed in the previous years, data/model comparisons will be made for the specific harbor environment chosen for the demonstration.

WORK COMPLETED

In FY2007, engineering field tests were conducted in Jacksonville Quarry, Jacksonville, PA, located about 30 miles East of State College, PA. The quarry has a surface area of approximately 100 x 150 m and 12 m in depth. The bottom and sides of the quarry are limestone. Due to conversion of compressional wave to shear wave energy, the limestone walls were predicted to not be very reflective at the transmit frequencies. This was born out in the measurements and it was demonstrated that an acoustic beam could be formed using an array of 4 Lubell sources.

In preparation for an engineering test in July 2007 at Coddington Cove, a hydrophone measurement system was specified and purchased. 12 Reson TC-4032 hydrophones were purchased with a receive response down to 5 Hz. Hydrophone extension cables of various lengths (50 m, 100 m, and 150 m) were also purchased allowing great flexibility in outfitting a harbor for acoustic measurements. In addition, a self-contained multi-channel signal distribution and conditioning system was specified and put together. Signal distribution of up to 24 channels is provided at the input of the patch panel. 16 of the channels are fed to a Precision Instruments pre-amplifier/filter for conditioning before distribution for analysis and archiving. System gain and filtering for each channel is programmable via an RG45 interface using a laptop computer. The system was designed to allow expansion to more channels as required.

The hydrophone measurement system was field tested at Coddington Cove in July 2007. An array of 12 hydrophones was laid out along 4 radials with the assistance of the range-crew and Navy certified divers from NUWC. At the origin of the radials was a source monitoring phone mounted on the different sources at a distance of 1 m. Several different sources were used during the test including an HLF-1, slotted cylinder, J-15-1, J-9, and an array of J-11 sources. The focus of this work was to examine propagation conditions for a single source along radials with different aspects in the harbor. The CAV group used an array of 3 J-11 projectors to demonstrate their control algorithms as is reported under separate cover. CW tones ranging from 10 Hz to 1000 Hz were projected during the tests in order to determine the cutoff frequency for propagation. In addition LF linear sweeps from 50-1000 Hz were broadcast from a range craft at different locations in the harbor to examine spatial variability of propagation conditions and any contributions to the field from strong reflectors such as the moored carriers, piers, or breakwaters. Sound speed profile measurements were made twice a day by deploying a CTD from the range craft.

Along with the engineering test as Coddington Cove, supporting archival environmental data were assembled and reformatted for use in 3D acoustic propagation models. Electronic navigational chart data was acquired from the NOAA office of coast survey. Additional high-resolution bathymetry data and surficial sediment data was provided by NUWC. Along with the measured water column sound velocity data a spatial gridding of the harbor environmental properties was achieved. The original data, given on a semi-regular grid was then interpolated onto a finite element mesh grid over the later extent of the harbor. At each of the node points of the mesh, normal modes were calculated using Kraken[3]. With the modes calculated, the field could be simulated for any source location placed in the mesh using the pre-determined modes calculated at the mesh locations.

RESULTS

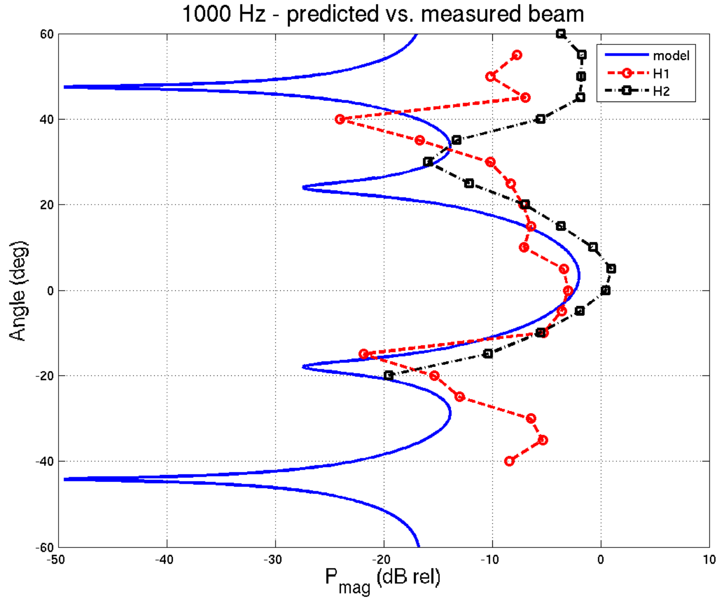

Fig 1. Beam pattern measured at 1kHz at two hydrophone positions in Jacksonville Quarry for 4 Lubell sources compared with free-field predictions.

Initial field testing at Jacksonville quarry demonstrated the ability to form an acoustic beam in the presence of vertical boundaries, as shown in Fig. 1. The beam formed at 1 KHz in the presence of vertical boundaries measured at two different hydrophone locations matched well with the beam predicted for sources in free space.

Analysis of the data collected during the July tests is ongoing. A preliminary result is the lack of strong scatterers observed in the pulsed LFM taken from multiple locations around the harbor. The dominant return from the pulsed signal appeared to come from a layer located within the seabed. Two-way travel time between the initial and reflected pulses shown in Fig. 2 indicated a sediment layer approximately 30 m into the sediment.

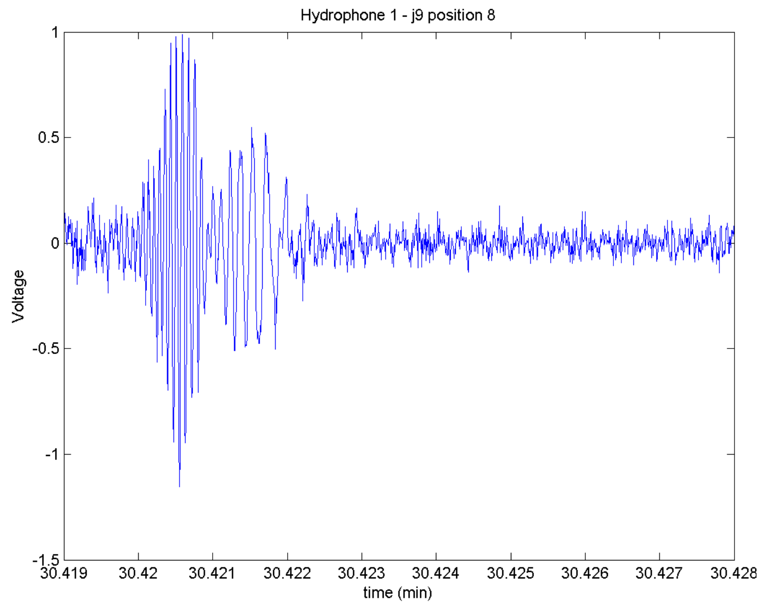

Fig. 2. Match filtered LMF signal showing initial pulse and reflected return. Two-way travel time indicated reflection is from a layer approximately 30 m in the sediment.

Similar returns were consistently seen in the data as the source was relocated in the harbor. Identification of a sediment layer from the data was later used in modeling acoustic propagation in the harbor.

For the mean harbor depth of 11 m and the surficial sediment data comprised of a sandy/silt material having a compressional sound speed of 1650 m/s, initial predictions indicated the environment would not support propagation that was observed in the field data. Most notable, the predictions indicated the modal cutoff frequency [4] to be about 80 Hz, however, propagation was observed out to 400 m below 30 Hz. Adding a layer of sandy material to the model with a sound speed of 1800 m/s at approximately 30 m depth, the model would predict propagation at the lower frequencies. With knowledge of the layer, *in-situ* sound water column sound speed data, and the bathymetry, a computer program was written to predict 3D acoustic propagation in Coddington Cove. The result for a 50 Hz cw source placed near the bottom is shown in Fig. 3. The model does not yet take into account vertical boundaries or scatterers, however it does reflect refraction effects and asymmetry in the field due the changes in the bathymetry and sediment types around the harbor. In particular, it shows enhanced propagation away from the source toward deeper parts of the harbor and increased losses in the shallower regions. Predictions at higher frequencies showed increased refraction effects and more complications in the field due to modal interference. At frequencies below about 100 Hz, only a single mode is predicted yielding generally cylindrical spreading behavior. A quick look at the field data agreed with the prediction, although further analysis must be done before the model can be validated.

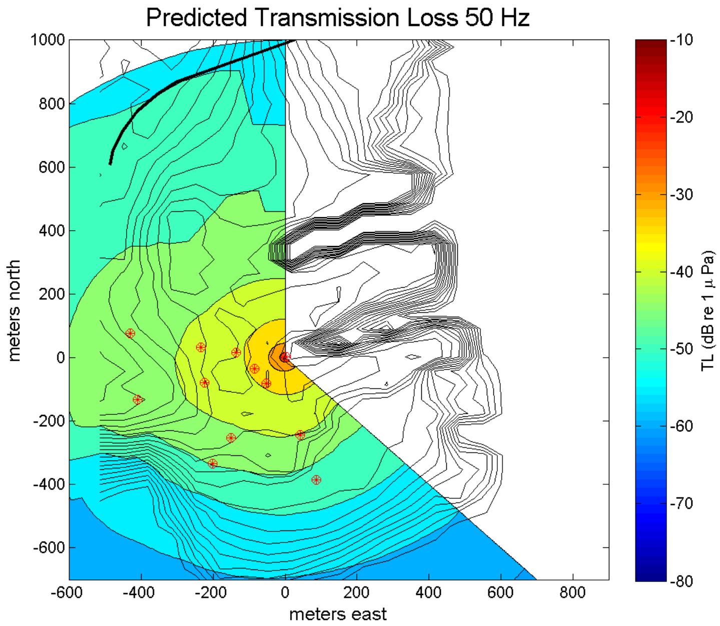

Fig 3. 3D prediction of acoustic field for 50 Hz point source in Coddington Cove. Contributions from vertical reflecting boundaries have not been added.

IMPACT/APPLICATIONS

Successful demonstration of the integrated defense system will provide a means for the Navy to protect valuable assets in port from the threat posed by covert swimmers. It is anticipated that systems of this type be installed initially in military harbors within the US. Installations would expand to deployment in military and important commercial harbors around the globe.

RELATED PROJECTS

Turbo Machinery Acoustic Source, M. Jonson (PI), Penn State University

Defense of Harbor and Near-Shore Naval Infrastructure, G.H. Koopmann (PI), Penn State University

Human Lung Response to Low-Frequency Underwater Sound, M. Hamilton (PI), Univ. of Texas Austin

NRL GelMan Underwater Surrogate, K. Simmonds (PI), Naval Research Lab.

Underwater Acoustics Bioeffects: Continuous Wave, E. Cudahy (PI), Naval Submarine Medical Research Lab.

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